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THE WEATHERING OF PLASTICS MATERIALS IN THE TROPICS. 4. POLYSUL--ETC(U)
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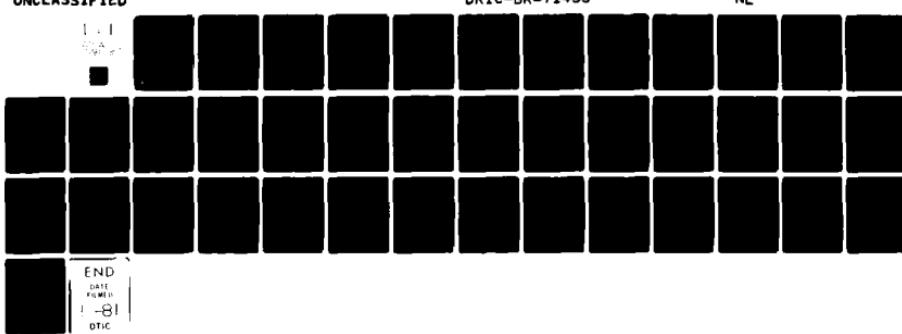
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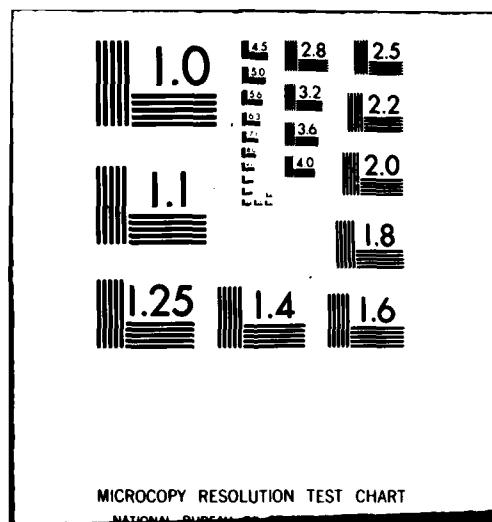
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THE WEATHERING OF PLASTICS
MATERIALS IN THE TROPICS

4. POLYSULPHONE

Report by

Procurement Executive, Ministry of Defence/British
Plastics Federation Joint Committee on the Behaviour
of Plastics Materials under Tropical Conditions



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Issued by

Procurement Executive, Ministry of Defence
Propellants, Explosives and Rocket Motor Establishment
Waltham Abbey

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Propellants, Explosives and Rocket Motor Establishment
Waltham Abbey
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SUMMARY

The report describes the effect of long term weathering on polysulphone. Both unpigmented samples and samples containing carbon black were exposed for up to 4 years at two tropical and one temperate site. Visual appearance, weight, tensile and flexural strength and electrical properties were recorded and used to monitor the effects of weathering on polysulphone. Unpigmented samples were found to embrittle rapidly while carbon black filled samples showed no loss of flexural strength and losses of ductility smaller than those observed with the natural material.

1 INTRODUCTION

The aims of this trial were to determine the extent to which certain mechanical and electrical properties of moulded polysulphone were retained on weathering. Polysulphone has been introduced as a transparent engineering thermoplastic having good high temperature performance, exceptional resistance to creep, and high toughness and rigidity. However, little information is available concerning the effect of long term weathering on these properties.

One grade of material was investigated with and without the addition of carbon black. Both unpigmented and carbon black filled specimens were exposed for periods of up to four years at two tropical sites in Australia and at one temperate site in the United Kingdom.

Specimens stored in the dark under controlled laboratory conditions at Innisfail, Australia and Waltham Abbey, UK, were tested at each withdrawal.

Details of the trial are given in the schedule (Appendix 1).

2 EXPERIMENTAL

2.1 Materials

The polysulphone used was "Udel" P1700 a product of Union Carbide. This was purchased in the natural and carbon black pigmented state (1.0 pph).

2.2 Specimens

Four types of mouldings were produced, all nominally 3.2 mm thick, under conditions recommended by the material suppliers.

a Tensile specimens: Dumb-bells (BS 2782, 301.11).

b Flexural specimens: 102 mm x 12.7 mm rectangular bars.

c Weight and dimensional change specimens: 102 mm diameter discs.

d Electrical properties specimens: 50.8 mm diameter discs.

2.3 Exposure

2.3.1 Temperate

The site is at the Propellants, Explosives and Rocket Motor Establishment (PERME), Waltham Abbey $1^{\circ}W$ $51^{\circ}N$) in Southern England and is semi-rural in character. Specimens were mounted in wooden frames facing south and at 45° to the horizontal.

2.3.2 Hot/Wet (Clearing)

The hot/wet cleared site is situated at the Joint Tropical Research Unit (now JTTRE), Innisfail, Australia ($146^{\circ}E$ $17^{\circ}S$). The site comprises an area of some 3500 m^2 jungle clearing, sloping down towards north and clear of trees so that specimens are exposed to the full effects of the sun, wind and rain in addition to the heat and humidity characteristic of the forest itself. The ground cover consists of grass which is regularly cut. Specimens were mounted in light alloy frames inclined at 45° to the horizontal facing north. Meteorological instruments are mounted within the cleared area.

2.3.3 Hot/Dry (Desert)

This is situated at Cloncurry about 400 miles SW of Innisfail ($140^{\circ}E$, $21^{\circ}S$) and comprises 18000 m^2 enclosed by a fence on level ground at the edge of a small airfield. Specimens are exposed to intense sunlight, long periods of low relative humidity, sparse rainfall and abrasion by windblown sand. The meteorological instruments are mounted about 1 km to the south without intervening obstructions. Specimens were mounted as in 2.3.2.

2.4 Control Specimens

Sets of control specimens were stored in conditioned rooms at JTRU and at PERME for testing at the beginning and end of the trial and at each withdrawal.

2.5 Conditioning of Specimens before Laboratory Testing

Specimens were conditioned for 28 days at $20 \pm 2^{\circ}\text{C}$ and $65 \pm 2\%$ Relative Humidity prior to testing.

2.6 Test Methods

2.6.1 Visual Assessment

Control specimens were maintained in the dark under conditions as in 2.5. At each withdrawal changes in appearance of exposed specimens were classified as chalking, cracking, crazing, erosion, dirt collection and colour, using a scale of increasing severity of 0 to 3.

2.6.2 Weight Changes

Conditioned specimens were weighed to the nearest mg before exposure. Weights were approximately 32 g. On withdrawal, loosely adherent matter was removed with a camel-hair brush and more strongly adherent matter (generally from areas shaded by the mounting channels) was wiped off with a soft tissue. Specimens were then conditioned and reweighed. Changes in weight were calculated as percentages of the original weight.

2.6.3 Dimensional Changes

Conditioned specimens were measured to 0.025 mm with vernier callipers before and after exposure and changes expressed as percentages of the initial dimensions.

2.6.4 Mechanical Properties

Measurements were generally made on five replicates. Sectional areas were determined by measuring dimensions to 0.025 mm and testing was carried out under a controlled atmosphere as in 2.5. Details of the test methods are given in Appendix 2.

3 RESULTS

3.1 Visual Assessment

The changes observed after four years exposure are given in Table 1.

TABLE 1
Appearance after Four Years Exposure

Polysulphone Type	Exposure Site	Colour ¹	Chalking	Cracking	Crazing	Pitting	Dirt Collection
Natural	Hot/Wet	3	1	0	3	3	1
	Hot/Dry	2	1	0	3	3	0
	Temperate	2	2	0	2	1	3
Black	Hot/Wet	-	3	0	3	3	1
	Hot/Dry	-	3	0	3	3	1
	Temperate	-	3	0	0	3	2

¹Colour change according to BS 2662: 5 = no change, 1 = severe change.

All others: 0 = none, 1 = slight, 2 = moderate, 3 = severe.

There was a marked "darkening" of the natural material at all three sites and also chalking, particularly of the black specimens. Cracking was absent but crazing and pitting occurred in both types particularly at the tropical sites. Most dirt collection occurred at the temperate site.

3.2 Weight Changes

These are given in Table 2.

TABLE 2
Weight Changes (% of Original Weight)

Exposure Time in Years	Natural			Black		
	Control	Hot/Wet	Hot/Dry	Control	Hot/Wet	Hot/Dry
0.5	< -0.1	-0.7	-0.1	< -0.1	-0.6	-0.3
1	-0.1	-1.2	-0.5	-0.1	-0.9	-0.5
2	-0.1	-2.8	-1.4	-0.1	-1.8	-1.2
4	-0.1	-6.0	-3.0	-0.1	-3.3	-2.5

3.3 Mechanical Properties

3.3.1 Tensile Properties

The results of tensile tests are summarised in Tables 3 and 4. Results are given as mean values. Detailed results are shown in Appendix 3.

Changes in mean values are plotted in Figs 1 to 3.

TABLE 3
Yield Strength and Breaking Strength (MPa)

Property	Type	Exposure Time (years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Control	Temperate Exposed
Yield strength	Natural	0	65.3	65.3	65.3	73.7	73.7
		$\frac{1}{2}$	77.6	)	)	72.8)
		1	69.9	) Did not yield	) Did not yield	74.0	) Did not yield
		2	74.3	)	)	72.7)
		4	73.5	)	)	72.1)
	Black	0	63.7	63.7	63.7	74.4	74.4
		$\frac{1}{2}$	75.7	75.0	76.0	72.7	73.0
		1	75.7	69.7	69.4	73.6	73.6
		2	72.5	72.7	73.2	72.8	71.6
		4	73.8	73.3	73.9	74.1	71.3
Breaking strength	Natural	0	50.1	50.1	50.1	50.1	50.1
		$\frac{1}{2}$	53.3	58.3	63.9	51.9	65.4
		1	47.6	49.1	50.4	53.0	60.7
		2	52.3	48.5	46.3	50.0	51.8
		4	50.0	48.1	47.2	52.4	55.9
	Black	0	50.4	50.4	50.4	50.4	50.4
		$\frac{1}{2}$	51.7	51.1	50.5	51.1	56.2
		1	54.3	47.8	47.1	49.9	49.9
		2	51.3	49.4	49.7	50.1	49.0
		4	50.4	53.7	50.4	51.6	54.0

TABLE 4
Yield Strain and Breaking Strain

Property	Type	Exposure Time (years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Control	Temperate Exposed
Yield strain (per cent)	Natural	0	7.7	7.7	7.7	7.7	7.7
		$\frac{1}{2}$	-	-	)	5.9)
		1	5.9	) Did	) Did	-	) Did
		2	5.5	) not	) not	6.1	) not
		4	5.2	) yield	) yield	5.9	) yield
	Black	0	8.8	8.8	8.8	8.8	8.8
		$\frac{1}{2}$	-	-	-	5.7	5.8
		1	5.9	5.9	5.9	3.0	3.0
		2	5.4	5.4	5.1	5.9	6.1
		4	5.2	5.1	5.1	5.0	5.7
Breaking strain (per cent)	Natural	0	89	89	89	89	89
		$\frac{1}{2}$	72	1.4	1.6	50	4.1
		1	86	2.3	2.3	97	1.6
		2	-	1.8	1.9	38	2.5
		4	57	2.2	2.1	-	2.4
	Black	0	62	62	62	62	62
		$\frac{1}{2}$	60	26	32	30	14
		1	151	43	42	89	22
		2	-	47	29	154	17
		4	34	8	13	193	40

Necking occurred with many of the specimens, resulting in a wide range of values of breaking strain being obtained in a large proportion of tests.

3.3.2 Flexural Properties

Flexural strength and flexural modulus results are given in Tables 5 and 6. Results are given as mean values. Detailed results are shown in Appendix 3.

Mean values are plotted in Figs 4 and 5.

TABLE 5
Flexural Strength (MPa)

Type	Exposure Time (years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Control	Temperate Exposed
Natural	0	94.1 ⁺				
	$\frac{1}{2}$	97.5	81.0	97.7*	93.2 ⁺	95.7 ⁺
	1	91.6 ⁺	73.4*	78.0*	96.8 ⁺	101 ⁺
	2	93.5 ⁺	70.6	65.4	95.3 ⁺	70.9
	4	103	74.9	70.9	98.8 ⁺	56.3
Black	0	91.0	91.0	91.0	94.6 ⁺	94.6 ⁺
	$\frac{1}{2}$	97.9	102	101 ⁺	92.1 ⁺	90.4 ⁺
	1	92.0 ⁺	99.4 ⁺	96.8 ⁺	97.8 ⁺	104 ⁺
	2	92.6 ⁺	100 ⁺	97.0 ⁺	94.6 ⁺	99.0 ⁺
	4	103	108 ⁺	104 ⁺	99.7 ⁺	91.4 ⁺

⁺Indicates that the specimens did not break, and the figure represents the mean strength at a deflection of 6.35 mm.

*Indicates that at least one of the specimens did not break.

TABLE 6
Flexural Modulus (GPa)

Type	Exposure Time (years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Control	Temperate Exposed
Natural	0					
	$\frac{1}{2}$	2.63	2.75	2.80	2.45	2.52
	1	2.46	2.55	2.56	2.61	2.81
	2	2.29	2.33	2.34	2.40	2.42
	4	2.66	2.69	2.70	2.74	2.80
Black	0					
	$\frac{1}{2}$	2.66	2.69	2.69	2.43	2.42
	1	2.42	2.45	2.44	2.65	2.70
	2	2.34	2.39	2.36	2.39	2.44
	4	2.72	2.77	2.67	2.72	2.52

3.4 Electrical Properties

The electrical results presented in Tables 7 to 10 are based entirely on the second and fourth year withdrawals.

TABLE 7
Permittivity at 1 MHz

Type	Site	2 Years	4 Years
Natural	Hot/Wet	2.95	3.28
	Hot/Dry	2.89	3.26
	Temperate	2.93	3.23
Natural Control	Tropical	2.91	3.21
	Temperate	2.91	3.17
Black	Hot/Wet	2.97	3.29
	Hot/Dry	2.95	3.28
	Temperate	2.91	3.22
Black Control	Tropical	2.96	3.25
	Temperate	2.88	3.23

TABLE 8
Loss Tangent at 1 MHz

Type	Site	2 Years	4 Years
Natural	Hot/Wet	0.0059	0.0081
	Hot/Dry	0.0056	0.0086
	Temperate	0.0051	0.0070
Natural Control	Tropical	0.0050	0.0067
	Temperate	0.0045	0.0062
Black	Hot/Wet	0.0052	0.0071
	Hot/Dry	0.0056	0.0074
	Temperate	0.0048	0.0064
Black Control	Tropical	0.0053	0.0070
	Temperate	0.0046	0.0062

TABLE 9
Surface Resistivity (Log₁₀ OHMS)

Type	Site	2 Years	4 Years
Natural	Hot/Wet	15.57	14.29
	Hot/Dry	11.54	12.55
	Temperate	14.54	15.3
Natural Control	Tropical	15.57	14.21
	Temperate	13.93	15.3
Black	Hot/Wet	15.57	15.00
	Hot/Dry	11.73	11.11
	Temperate	14.57	15.3
Black Control	Tropical	15.57	13.91
	Temperate	14.57	15.3

TABLE 10

Volume Resistivity ($\log_{10} \frac{A}{t}$ OHM.CM)

Type	Site	2 Years	4 Years
Natural	Hot/Wet	16.10	15.59
	Hot/Dry	14.76	15.90
	Temperate	12.86	15.7
Natural Control	Tropical	16.10	15.42
	Temperate	13.05	15.7
Black	Hot/Wet	16.11	15.51
	Hot/Dry	14.36	15.82
	Temperate	12.90	15.7
Black Control	Tropical	16.10	16.10
	Temperate	13.16	15.7

4 DISCUSSION4.1 Visual Changes and Weight Measurements

Unpigmented polysulphone darkens in colour to a reddish brown hue inside 6 months at the tropical sites. This change is the result of photolytic breakdown of the polymer, hence the fact that samples at the tropical sites show change before temperate site specimens. Fortunately the new colour centres produced filter the damaging solar UV radiation and the rate of degradation tends to decrease with time of exposure. The surface nature of the weathering of polysulphone is highlighted by the significant degree of pitting erosion and dirt collection shown by both the natural and black materials. The black and natural materials also show severe surface crazing inside 6 months at the tropical site - a phenomenon also shown by polycarbonate on weathering. The black polysulphone specimen, in common with other black pigmented polymers lost lustre and suffered chalking inside a year's exposure at all sites.

From the weight change measurements which were only made at the tropical sites it is seen that for both natural and black polysulphone there is a

continuous loss in weight over the whole of the 4 year trial. These weight changes are greater for the natural than for the black material and for both materials the weight losses observed are more pronounced at the hot/wet than the hot/dry site.

4.2 Tensile Properties

The strength at yield and the strength at break of the black polysulphone showed very little difference between the exposed and control specimens at all three sites. At the tropical sites there was a small overall increase in strength at yield, which was also seen in the controls, but the temperate specimens showed virtually no change. Breaking strength was unchanged at all sites. There is an apparent decrease in yield strain, the extent of which is difficult to define, due to the large scatter of the initial control results, caused by isolated high values.

Because necking occurred during many of the tests, elongation at break results are very scattered and of little practical value. However, after 4 years of tropical exposure embrittlement had occurred, particularly at the hot/wet site where breaking elongation had decreased to 8% from its original value of about 60%.

Whereas the yield and tensile strengths of the black polysulphone showed little significant change during exposure, yield was no longer observed in the natural material, after only 6 months exposure at all sites, the breaking elongation having decreased to 4% at the temperate site and less than 2% at both tropical sites. Clearly the material has become brittle inside 6 months. On the other hand, the tensile strength increased over the first six months at all sites. At subsequent withdrawals there was a decrease, but even after 4 years tropical exposure it was no different from the controls. Similar changes were not observed in the control specimens and it can be inferred that they are attributable to weathering effects and not to ageing.

Tropical exposure produces a greater loss in ductility than temperate exposure, but there is little difference between the two tropical sites. The nature of the small changes found in tensile strength is clarified by considering the stress/strain curve for an unexposed natural polysulphone specimen (Fig 6). As the material weathers the original stress/strain curve is in effect retraced (ABC) but after 6 months the specimen has lost much of its elongation and its tensile strength is to the left of B but still above

its original value C. With further exposure tensile strength is reduced slightly. It is worth noting that the energy to break the specimen, that is the area under the curve, is reduced for weathered specimens and indicates that the impact strength of natural polysulphone will be severely reduced by weathering.

4.3 Flexural Properties

The flexural strength and flexural modulus values of black specimens showed little variation between exposed and control specimens in all cases and relatively little change overall. There is, however, a tendency for all the black tropical specimens to show a general increase in flexural strength with time, similar to that obtained for yield strength of the tensile specimens. On the other hand, the flexural strength of the natural material falls appreciably at all the exposure sites. It is surprising that the temperate site shows more degradation in 4 years than either of the tropical sites. However, flexural properties are to a marked extent dependent on the surface properties of the material, the nature and condition of which must be changing continuously. The apparent anomaly may be due to this as also may be the apparent fluctuations observed in flexural modulus values.

4.4 Electrical Properties

All samples showed increasing permittivity with similar rate of change over the last two years with little difference between natural and black, control and exposed conditions. Natural samples exhibited a higher rise in loss tangent for temperate and tropical conditions than control samples, whereas for black samples control and exposed showed the same increase. Hot/dry conditions had a more pronounced effect (lower resistivity) than other exposed conditions. As regards volume resistivity no distinct difference between control and exposed samples was observed.

4.5 General

The results of this trial indicate that while natural polysulphone shows little change in tensile strength as a result of outdoor exposure, it rapidly became brittle as indicated by the decrease in elongation at break. This embrittlement together with the observed surface degradation suggest that the impact resistance of this material would be adversely affected. In

comparison black polysulphone shows no loss of flexural strength and less loss of ductility and would therefore be expected to show a smaller loss of impact resistance. The results of a recent investigation confirm this. It has been found that if polysulphone is not pigmented with carbon black its impact resistance falls sharply as a result of outdoor exposure.²

As part of a programme to evaluate the stability of polysulphone, film of the unpigmented material has been examined after natural weathering and after exposure to artificial light. The results of tensile and UV spectra measurements indicate that the material has a marked sensitivity to solar UV radiation.¹ Whilst the chemical entities formed have the effect of reducing the rate of subsequent degradation, a 30 μm thick film becomes extremely brittle after only a few days of temperate exposure. The spectral sensitivity of the film has been determined by following changes in its UV spectrum and it has been found that it is only affected by wavelengths below about 330 nm. Making use of this property, polysulphone film has been used to monitor solar UV radiation and it is currently being used as a personnel dosimeter in medical applications.³

5 REFERENCES

1	Davis A, Deane G H W, Diffey B L	Nature, <u>261</u> , 169 (1976)
2	Barker S J	ICI Plastics Division Private Communication, 1977
3	Challoner A V J, Corless D, Davis A, Deane G H W, Diffey B L, Gupta S P, Magnus I A	Clinical and Experimental Dermatology, <u>1</u> , 175 (1976)

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APPENDIX 1

Trial Schedule

Subject: Plastics - Polysulphone.

1 Sponsor: Joint Services Research & Development Committee on Plastics.

Manufacturers: Granules from Union Carbide. Mouldings by PERME Waltham Abbey.

2 Purpose of Trial: To study the rates of degradation as shown by changes in physical properties of polysulphone, when exposed to tropical and temperate outdoor climates.

3 Scope of Trial:

Number of types	- 8
Number of replicates	- 5 of types 1A, 1B, 2A, 2B, 3A, 3B. 3 of types 4A, 4B.
Number of withdrawals	- 4
Number of sites	- 2 tropical, 1 temperate.
Number of specimens	- on sites 288 tropical 144 temperate controls 180 " 180 " totals 468 324

4 Exposure:

Sites	- Hot/wet, clearing Hot/dry	} tropical
	Rural	temperate
Types	- See Appendix 2	
Specimens	- Test pieces on Appendix 2	
Methods	- Specimens held at edges in aluminium channel on stands at 45° facing north in Australia and South in UK.	
Controls	- One set stored in conditioned room at JTRU and at PERME for testing at beginning and end of trial and at each withdrawal.	

APPENDIX 1

5 Assessment: Visual on site

Tensile strength and elongation
on types 1A and B (5 replicates)

Flexural strength
on types 2A and B (5 replicates)

Weight and dimensions
on types 3A and B (2 replicates)

Volume and Surface Resistivity
on types 3A and B (3 replicates)

Loss Tangent and Permittivity
on types 4A and B (3 replicates)

See Appendix 2

6 Withdrawal Programme: 6 months
12 months
24 months
48 months

7 Meteorological Data: Routine

8 Reports: At each withdrawal

9 Dates: Estimated exposure 1967

APPENDIX 2

Specimens and Methods of Test

1 Types of Specimen

Each specimen in this trial is a test-piece of P.1700 grade material as

- (A) natural with no additives
- (B) carbon black-filled

injection moulded into pieces of

- (1) 216 mm x 19 mm shaped as BS 2782, 301.11
- (2) 102 mm x 12.7 mm rectangular
- (3) 102 mm dia discs
- (4) 50.8 mm dia discs

at 3.2 mm thick.

Number of specimens required:

<u>Type</u>	<u>Tropical</u>		<u>Temperate</u>	
	<u>2 Sites</u>	<u>Controls</u>	<u>1 Site</u>	<u>Controls</u>
1A	40	25	20	25
1B	40	25	20	25
2A	40	25	20	25
2B	40	25	20	25
3A	40	25	20	25
3B	40	25	20	25
4A	24	15	12	15
4B	24	15	12	15

2 Methods of Test

Tensile Strength and Elongation

Apparatus

The testing machine shall be capable of applying a load in tension to a test piece gripped in wedge-type self-aligning grips. Provision shall be made for making simultaneous measurements of both load on the test piece to within

APPENDIX 2

2% and the distance between reference lines on the test piece to within 5% of the true values and preferably recording these values automatically on a load extension curve throughout the test.

Test Pieces

Five replicates shall be used for each test. The pieces shall be moulded shapes to BS 2782/1965, 301.11. When the test pieces have been selected to be the specimens for exposure, they shall not be cut or sanded in any way between withdrawal and testing.

Procedure

Before testing, the test pieces shall be conditioned for at least 28 days at $65 \pm 5\%$ rh and $20 \pm 2^\circ\text{C}$. The test shall be carried out at $20 \pm 2^\circ\text{C}$ immediately after removal from the conditioning atmosphere.

Reference lines shall be marked 50 mm apart on the central parallel/portion of the test pieces as shown in Fig 301.11 of BS 2782 and described in method 301J.

The width and thickness of the test pieces shall be measured at three points between the reference lines to the nearest 0.025 mm and the mean width and thickness calculated.

Each test piece shall be gripped with a fixed distance of 115 mm between grips and the load applied at a rate to give a rate of separation of the jaws of 25 mm/min to break.

Calculations

The tensile strength of each test-piece shall be calculated from the maximum load sustained and the original area of cross section and shall be expressed in Pascals. The elongation of each test piece at yield and at break shall be expressed as a percentage of the original distance between the reference lines. Both tensile strength and elongation shall be reported respectively as the arithmetic means of the five readings.

Report

The report shall state:

APPENDIX 2

- 1 The individual test results
- 2 The test pieces which broke at the grips
- 3 The tensile strength of the material
- 4 The elongation and strength at yield*
- 5 The elongation at break

*If obtainable (weathered specimens may not exhibit a yield)

Flexural Strength and Elastic Modulus in Flexure

Apparatus

The testing machine shall be capable of applying a bending load by means of a loading block parallel to and exactly mid-way between two parallel supporting blocks placed 50 ± 0.75 mm apart. Provision shall be made for making simultaneous measurements of both load on the test piece and its deflection at its midpoint to within 2% of the true values, and for recording these values automatically on a load/deflection curve. The contact edges of the supporting and loading blocks shall have a radius of 1.6 mm and shall be not less than 25 mm long.

Test Pieces

Five replicates shall be used for each test. The dimensions shall be nominally 102 mm x 12.7 mm x 3.2 mm, the larger surfaces, being called the faces. When the test pieces have been selected to be the specimens for exposure, they shall not be cut or sanded in any way between withdrawal and testing.

Procedure

Before testing, the test pieces shall be conditioned for at least 28 days at $65 \pm 5\%$ rh and $20 \pm 2^\circ\text{C}$. The test shall be carried out at $20 \pm 2^\circ\text{C}$ immediately after removal from the conditioning atmosphere.

The width and thickness of the test pieces shall be measured at three points along the length to the nearest 0.025 mm and the mean width and thickness calculated. The points of measurement shall not be within 25 mm of either end of the test piece.

The test piece shall be placed symmetrically across the two supporting blocks with the face which was uppermost on the exposure rack, ie the

APPENDIX 2

weathered face, resting on the two supports. After having ensured that a suitable load-measuring scale is in use, the load shall be applied by moving the loading block relative to the support at a substantially constant rate of approximately 5 mm/min.

The load and deflection shall be recorded continuously until the test piece breaks or until the deflection is 6.3 mm.

Calculations

1 If the test piece breaks, the flexural strength (Pa)

$$= \frac{1.5 WL}{BD^2}$$

where W = load N at fracture

L = distance between supports in metres

B = width of test piece in metres

D = thickness of test piece in metres

2 If the test piece does not break, the stress at 6.3 mm deflection (Pa)

$$= \frac{1.5 WL}{BD^2}$$

where W = load in Newtons at 6.3 mm deflection

L = distance between supports in metres

B = width of test piece in metres

D = thickness of test piece in metres

3 Elastic modulus in flexure (Pa)

$$= \frac{wL^3}{4BD^3 e}$$

where w = load in Newtons

e = deflection in metres

as read from the load/deflection curve at a point to be agreed.

Report

The report shall state:

APPENDIX 2

- 1 The number of test pieces which fractured and the individual results of cross-breaking strength.
- 2 The number of test pieces which deflected to 6.3 mm and the individual results of load at 6.3 mm deflection.
- 3 The individual results of elastic modulus in flexure if required.

Volume Resistivity and Surface

The test pieces, discs 102 mm diameter and 3.2 mm thick, shall be tested according to BS 2782, Part 2, 1965, Method 204C, except that the pieces shall not be dried and then immersed in water but tested after conditioning for 28 days at $65 \pm 5\%$ rh and $20 \pm 2^{\circ}\text{C}$. Three replicates of each type of specimen shall be tested and the mean of this logarithms of the readings reported.

Loss Tangent and Permittivity

The test pieces, discs 50.8 mm diameter and 3.2 mm thick, shall be tested according to BS 2782, Part 2, 1965, Method 207A, at 1 MHz.

Three replicates of each type of specimen shall be tested and the arithmetic mean reported.

APPENDIX 3

Mechanical Properties of Controls and Exposed Specimens

Exposure			Changes %			Tensile Properties				Flexural Properties	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	ϵ_y %	S_b MPa	ϵ_b %	S MPa	E_f GPa
Tropical Laboratory	Natural Control	0				68.0		48.2		93	
						61.3		55.7		61	
						67.2		53.8		66	
						61.2		44.7		66	
						69.0		48.3		74	
		Mean				65.3	7.7	50.1	50.1	72	
		6	< -0.1	Nil	Nil	77.9		53.1	51	97.2	2.60
						76.5		53.0	72	97.3	2.60
						77.9	Not measured	53.4	94	98.6	2.69
						77.9		53.2	41	97.2	2.66
						77.9		53.9	104	97.2	2.60
		Mean				77.6		53.3	72	97.5	2.63
		12	-0.1			68.9	5.8	46.5	36	91.0*	2.43
						69.7	5.8	47.3	68	91.0*	2.43
						70.3	5.8	47.6	94	91.0*	2.46
						70.3	5.8	47.8	104	91.7*	2.43
						70.3	6.1	48.8	128	93.4*	2.55
		Mean				69.9	5.9	47.6	86	91.6*	2.46
		24	-0.1	+0.2	-0.1	74.2	5.3	52.7		92.7*	2.25
						74.2	5.4	51.4		94.0*	2.29
						74.7	5.3	50.5		95.1*	2.29
						74.1	5.6	56.2		92.8*	2.29
						74.1	5.7	50.8		92.9*	2.31
		Mean				74.3	5.5	52.3		93.5*	2.29
		48	-0.1	+0.3	+0.3	74.0	5.2	50.0	89.9	102	2.60
						74.1	5.3	49.8	21.8	107	2.63
						74.1	5.2	50.0	7.8	102	2.65
						71.0	5.2	49.8	106.9	102	2.72
						74.4	5.2	50.4	56.8	101	2.72
		Mean				74.1	5.2	50.0	56.6	102	2.66

*Did not break, strength at 6.3 mm deflection

Tensile properties: S_y = yield strength S_b = breaking strength
 ϵ_y = yield strain ϵ_b = breaking strain

Flexural properties: S = flexural strength
 E_f = flexural modulus

APPENDIX 3

Exposure			Changes %			Tensile Properties				Flexural Properties	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa
Tropical Laboratory Controls Block Controls	0	0				65.0		65.4		103	
						63.9		45.6		103	
						64.0		45.7		79	
						61.8		46.5		90	
								49.0		79	Not measured
		Mean				63.7	8.8	50.4	50.4	91	
	6	< -0.1	Nil	Nil		81.4		52.8	74	97.2	2.66
						74.1		51.1	54	98.6	2.63
						73.8	Not measured	50.9	39	98.6	2.66
						74.5		-	-	96.6	2.66
						74.5		51.8	72	98.6	2.66
		Mean				75.7		51.7	60	97.5	2.66
	12	-0.1				74.4	5.9	54.9	142	93.1*	2.43
						75.8	6.1	53.9	146	90.9*	2.41
						77.2	5.8	56.3	176	92.1*	2.41
						75.8	5.8	53.3	150	93.1*	2.43
						75.1	6.0	52.9	140	91.0*	2.41
		Mean				75.6	5.9	54.2	151	92.0*	2.42
	24	-0.1	-0.1	Nil		73.4	5.2	52.9		93.5*	2.35
						73.2	5.7	50.3	Not measured	92.4*	2.33
						73.5	5.7	50.3		92.4*	2.37
						69.9	5.4	51.7		92.4*	2.33
						72.4	-	51.4		92.4*	2.33
		Mean				72.5	5.4	53.1		92.6*	2.34
	48	-0.1	-0.1	+0.3		73.4	5.1	49.3	34	102	2.72
						74.0	5.2	50.9	51	102	2.66
						74.0	5.3	50.6	12	104	2.71
						73.9	5.2	50.4	21	105	2.78
						73.8	5.2	50.6	51	103	2.73
		Mean				73.8	5.2	50.4	34	103	2.72

*Did not break, strength at 6.3 mm deflection

APPENDIX 3

Exposure			Changes %			Tensile Properties				Flexural Properties	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	ϵ_y %	S_b MPa	ϵ_b %	S MPa	E_f GPa
Temperate Black Controls	0	0				73.2	Not measured	All samples broke in grips so not recorded	Not measured	95.6*	Not measured
						75.5				95.0*	
						73.8				95.6*	
						75.4				92.8*	
						74.3				94.2*	
		Mean				74.7				94.6*	
	6	6				72.4		50.8		92.1*	2.34
						72.4		51.1		93.2*	2.52
						72.4		51.0		91.0*	2.39
						72.4		51.6		92.1*	2.48
						73.9		51.1		92.1*	2.42
	Mean					72.7	5.7	51.1	30	92.1*	2.43
	12	12				73.7	3.0	50.0	106	98.6*	2.66
						73.0	2.9	50.0	96	98.6*	2.63
						74.4	2.8	50.6	106	98.6*	2.65
						73.0	3.2	49.6	83	95.9*	2.65
						73.7	3.0	49.3	52	97.2*	2.66
	Mean					73.6	2.8	49.9	89	97.8*	2.65
	24	24				73.8	5.9	48.1	143	96.6*	2.43
						72.1	5.9	50.3	102	93.4*	2.42
						72.4	5.7	50.0	107	93.8*	2.36
						72.8	5.8	51.1	209	95.2*	2.40
						73.1	6.1	51.0	211	93.8*	2.36
	Mean					72.8	5.9	50.1	154	94.6*	2.39
	48	48				75.0	4.8	53.9	289	99.4*	2.74
						74.1	4.9	52.0	177	100.0*	2.75
						74.6	5.0	50.4	152	99.1*	2.64
						73.5	5.1	51.2	201	99.8*	2.78
						73.3	5.1	50.3	148	100.0*	2.71
	Mean					74.1	5.0	51.6	193	99.7*	2.72

*Did not break, strength at 6.3 mm deflection

APPENDIX 2

Exposure			Changes %			Tensile Properties				Flexural Properties	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	ϵ_y %	S_b MPa	ϵ_b %	S MPa	E_f GPa
Temperate	Natural	0									
		Mean									
		6				No yield		69.0	4.5	94.1*	2.44
								62.5	3.3	96.1*	2.56
								65.4	3.3	96.1*	2.57
								58.9	2.8	97.2*	2.54
								71.0	6.5	95.2*	2.48
		Mean						65.4	4.1	95.7	2.52
		12				No yield		58.3	1.6	98.6*	2.79
								61.8	1.6	103.4*	2.85
								58.6	-	102.1*	2.79
								60.2	1.4	102.1*	2.85
								64.8	1.7	98.6*	2.79
		Mean						60.7	1.6	101.0	2.81
		24				No yield		51.5	2.4	70.3	2.43
								51.3	2.5	71.0	2.43
								52.1	2.6	71.0	2.59
								51.8	2.4	71.0	2.48
								52.3	2.6	71.0	2.36
		Mean						51.8	2.5	70.9	2.42
		48				No yield		58.9	2.7	61.9	2.80
								59.1	2.6	54.0	2.80
								49.0	2.0	52.9	2.80
								56.6	2.5	-	-
								-	-	-	-
		Mean						55.9	2.4	56.3	2.80

*Did not break, strength at 6.3 mm deflection

APPENDIX 3

Exposure			Changes %			Tensile Properties				Flexural Properties	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	ϵ_y %	S_b MPa	ϵ_b %	S MPa	E_f GPa
Temperature Black		0									
		Mean				71.7		66.4		95.2*	2.43
		6				72.4		60.7		87.1*	2.36
						73.1		52.0		88.3*	2.40
						73.8		51.0		86.1*	2.46
		Mean				73.8	5.8	56.2	14	90.4*	2.42
		12				73.7	3.0	50.0	25	102.1*	2.79
						73.0	2.9	50.0	20	103.4*	2.69
						74.4	2.8	50.6	20	104.8*	2.63
						73.0	3.2	49.6	24	104.8*	2.61
		Mean				73.7	3.0	49.3	20	103.4*	2.79
		24				71.4	6.1	48.8	13	98.9*	2.45
						72.0	6.1	49.0	7	98.9*	2.45
						71.7	6.1	49.9	8	98.9*	2.47
						71.7	6.0	49.2	17	98.3*	2.41
		Mean				71.0	6.1	48.2	42	100.0*	2.45
		48				71.6	6.1	49.0	17	99.0*	2.45
						71.9	5.4	53.7	25	91.4*	2.47
						71.2	5.2	-	-	-	-
						70.6	6.0	55.1	22	90.5*	2.61
						71.0	6.0	54.4	54	92.0*	2.53
		Mean				71.6	6.1	52.9	60	91.5*	2.47

*Did not break, strength at 6.3 mm deflection

APPENDIX 3

Exposure			Changes %			Tensile Properties				Flexural Properties	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	ϵ_y %	S_b MPa	ϵ_b %	S MPa	E_f GPa
Hot/Wet Cleared Site Natural		0									
		Mean									
		6	-0.7	Nil	Nil	No yield	60.3	1.4	80.0	2.82	
							57.8	1.4	83.4	2.76	
							57.1	1.4	83.4	2.64	
							59.0	1.4	77.3	2.78	
							57.4	1.4			
		Mean					58.3	1.4	81.0	2.75	
		12	-1.2	Nil	Nil	No yield	49.0	2.3	70.3	2.59	
							46.9	2.2	69.0	2.53	
							50.1	2.4	68.5	2.49	
							49.4	2.3	79.0*	2.57	
							50.1	2.5	80.3*	2.59	
		Mean					49.1	2.3	73.4	2.55	
		24	-2.8	Nil	+0.1	No yield	47.0	1.6	66.1	2.28	
							48.2	1.9	71.3	2.33	
							46.8	1.7	73.0	2.37	
							49.9	1.9	69.7	2.32	
							50.7	2.0	73.0	2.37	
		Mean					48.5	1.8	70.6	2.33	
		48	-6.0	+0.2	+0.1	No yield	49.4	2.2	75.2	2.80	
							47.0	2.1	74.0	2.64	
							47.2	2.1	79.6	2.72	
							49.0	2.2	76.6	2.68	
							47.9	2.2	69.0	2.59	
		Mean					48.1	2.2	74.9	2.68	

*Did not break, strength at 6.3 mm deflection

APPENDIX 2

Exposure			Changes %			Tensile Properties				Flexural Properties	
Site	Type	Months	Weight	Length	Breadth	s_y MPa	ϵ_y %	s_b MPa	ϵ_b %	s MPa	E_f GPa
Not/Cleared	Block	0									
		Mean									
		6	-0.6	M11	M11	74.5 75.2 75.9 74.5	Not measured	50.3 51.0 52.0 51.2	25 24 30 25	103.4 99.3 103.4 103.4	2.69 2.72 2.69 2.66
		Mean				75.0		51.1	26	102.4	2.69
		12	-0.9	M11	M11	69.6 69.3 69.3 69.7 70.7	5.8 5.8 5.8 6.1 6.0	47.5 50.5 45.6 47.2 46.9	52 30 46 50 48	99.3 ^a 100.3 ^a 99.6 ^a 98.7 ^a 99.3 ^a	2.41 2.46 2.46 2.46 2.46
		Mean				69.7	5.9	47.5	43	99.4 ^a	2.46
		24	-1.8	M11	M11	72.6 72.6 72.6 72.9	5.4 5.3 5.4 5.4	49.4 49.2 49.4 49.4	36 83 29 39	100.5 ^a 100.6 ^a 101.0 ^a 99.0 ^a	2.38 2.38 2.39 2.39
		Mean				72.7	5.4	49.4	46	100.2 ^a	2.39
		48	-3.3	+0.2	+0.4	72.8 73.3 73.8 73.4 73.4	5.2 5.1 5.1 5.1 5.0	49.6 51.6 67.5 49.8 50.2	13.8 5.6 5.6 - 5.5	105 ^a 105 ^a 108 ^a 110 ^a 110 ^a	2.80 2.72 2.78 2.80 2.76
		Mean				73.3	5.1	53.7	7.6	108 ^a	2.77

^aDid not break, strength at 6.3 mm deflection

APPENDIX 3

Exposure			Changes %			Tensile Properties				Flexural Properties	
Site	Type	Months	Weight	Length	Breadth	s_y MPa	ϵ_y %	s_b MPa	ϵ_b %	s MPa	E_f GPa
Hot/Dry Cleared Site	Natural	0									
		Mean									
		6	-0.1	Nil	Nil	65.9	1.6	95.2	2.66	61.8	1.4
						61.0	1.6	101.6*	2.80	63.4	-
						67.2	1.8	100.7*	2.91	67.2	1.8
		Mean				63.9	1.6	97.7	2.80	50.6	2.3
		12	-0.5			50.7	2.4	84.1*	2.50	50.5	2.3
						51.5	2.5	77.6*	2.66	48.7	2.2
		Mean				50.4	2.3	77.9	2.50	51.5	2.5
		24	-1.4	+0.1	Nil	46.0	2.3	73.0	2.59	45.2	1.8
						47.3	1.8	77.4	2.53	48.2	1.8
		Mean				46.3	1.9	78.0	2.56	44.9	1.6
		48	-3.0	+1.0	+0.3	45.5	2.0	63.8	2.29	49.3	2.2
						45.4	2.0	63.8	2.36	47.2	2.0
		Mean				48.8	2.1	66.9	2.32	47.2	2.0
						47.2	2.1	66.9	2.36	44.9	1.6
		Mean				47.2	2.1	65.4	2.36	46.3	1.9
						47.2	2.1	65.4	2.34	45.5	2.0
		Mean				47.2	2.1	69.5	2.70	49.3	2.2
						47.2	2.1	72.9	2.66	45.4	2.0
		Mean				47.2	2.1	70.2	2.66	48.8	2.1
						47.2	2.1	69.1	2.70	46.3	1.9
		Mean				47.2	2.1	71.9	2.80	45.5	2.0
						47.2	2.1	70.7	2.71	49.3	2.2

*Did not break, strength at 6.3 mm deflection

APPENDIX 3

Exposure			Changes %			Tensile Properties				Flexural Properties	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	ϵ_y %	S_b MPa	ϵ_b %	S MPa	E_f GPa
Hot/dry	Block	0									
		Mean									
		6	-0.3	Nil	Nil	73.1 74.1 84.8 74.1 74.1	Not measured	49.2 50.6 50.6 51.4 50.9	31 26 39 30 33	100.6* 102.0* 100.6* 100.0* 100.7*	2.61 2.66 2.73 2.72 2.73
		Mean				76.0		50.5	32	100.8*	2.69
		12	-0.5	Nil	Nil	70.0 68.5 69.3 70.3 68.7	5.9 5.6 5.9 5.9 6.2	48.1 46.6 47.2 47.5 46.1	40 52 49 34 38	96.6* 94.5* 95.3* 97.1* 100.7*	2.45 2.41 2.46 2.44 2.45
		Mean				69.4	5.9	47.1	42	96.8*	2.44
		24	-1.2	Nil	Nil	72.9 72.8 73.6 73.8 73.0	5.1 5.0 5.2 4.9 5.3	52.9 48.9 46.9 49.9 49.8	- 24 - - 33	93.6* 97.9* 99.0* 99.6* 95.1*	2.33 2.32 2.40 2.42 2.33
		Mean				73.2	5.1	49.7	29	97.0*	2.36
		48	-2.5	+0.4	+0.1	73.4 73.1 74.1 74.7 74.1	5.3 5.1 4.9 5.1 5.2	52.1 48.6 49.5 51.0 50.9	5.8 9.9 5.7 22.9 17.8	103* 103* 105* 105* 106*	2.76 2.76 2.70 2.64 2.5*
		Mean				73.9	5.1	50.4	12.4	104*	2.67

*Did not break, strength at 6.3 mm deflection

FIG 1 TENSILE YIELD STRENGTH POLYSULPHONE

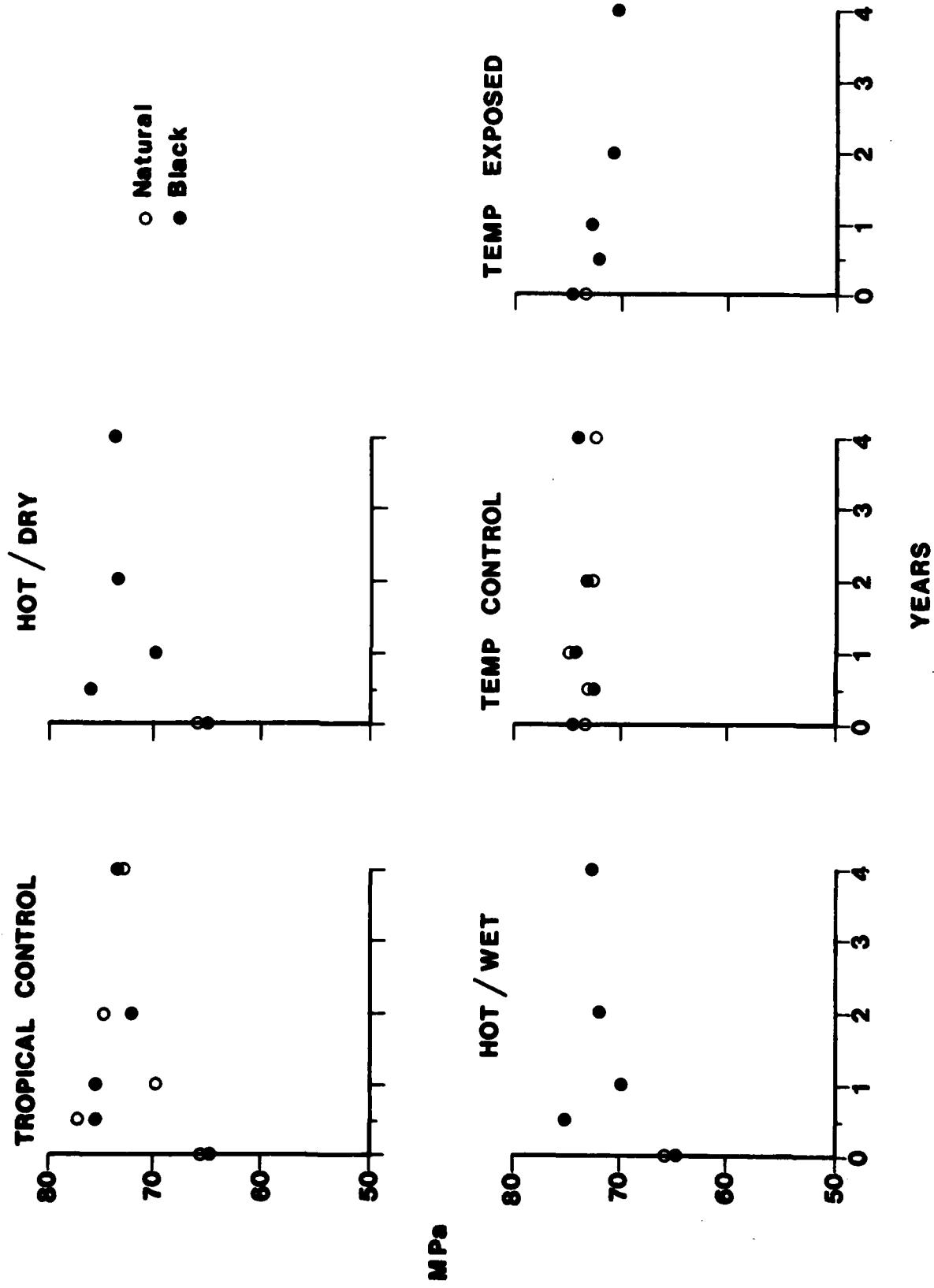


FIG 2 TENSILE BREAKING STRENGTH POLYSULPHONE

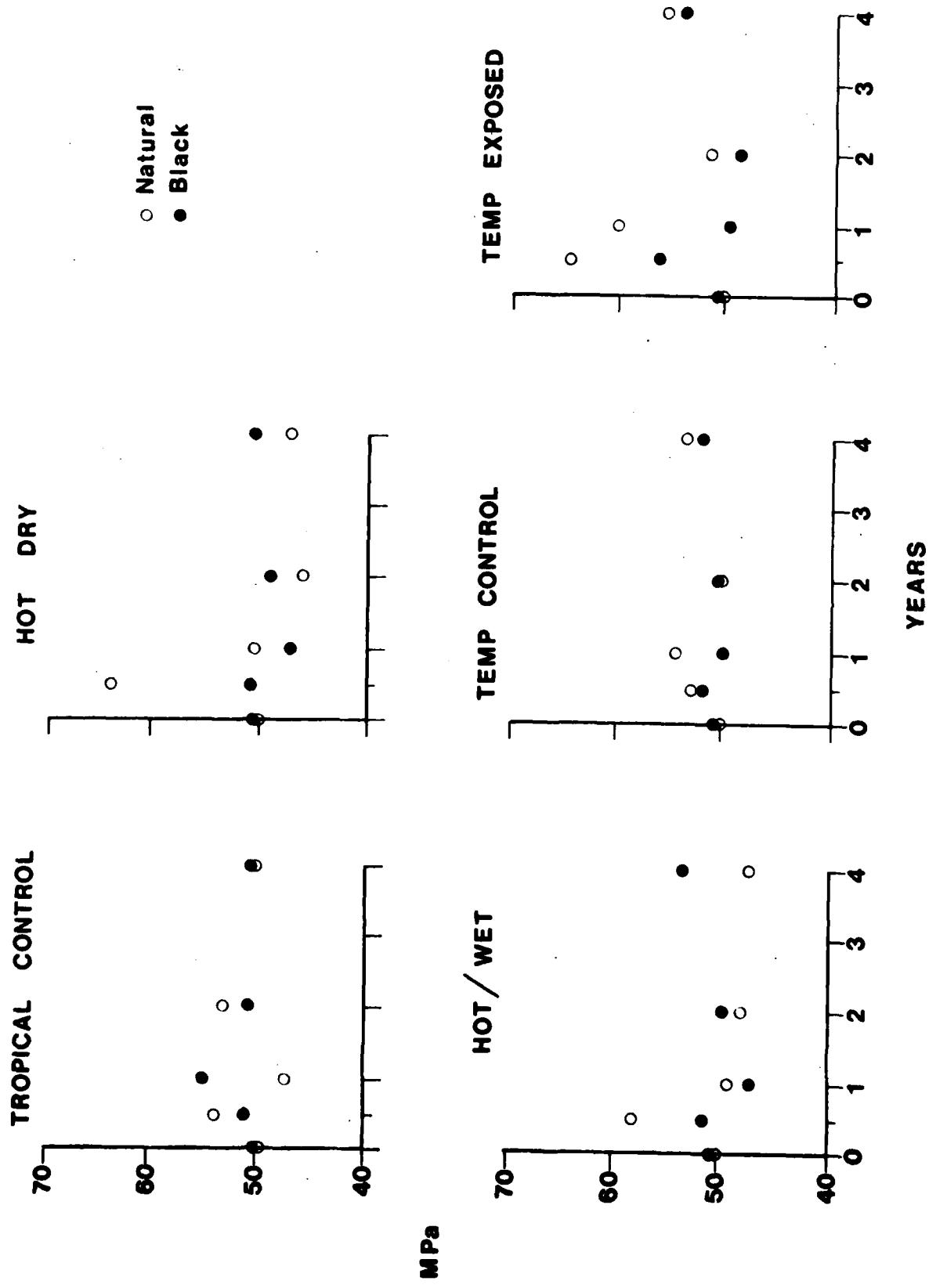


FIG 3 TENSILE YIELD STRAIN POLYSULPHONE

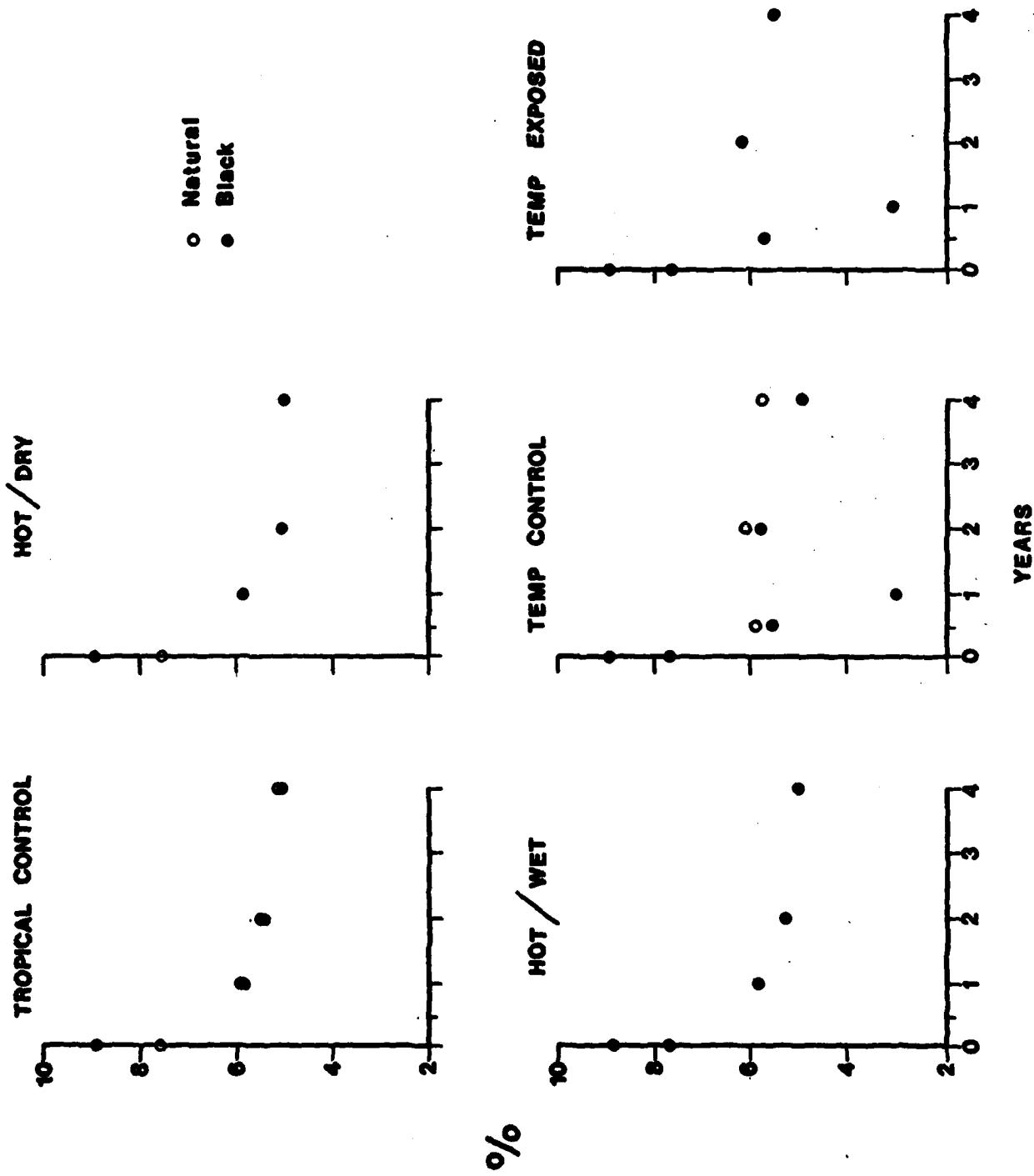


FIG 4 FLEXURAL STRENGTH POLYSULPHONE

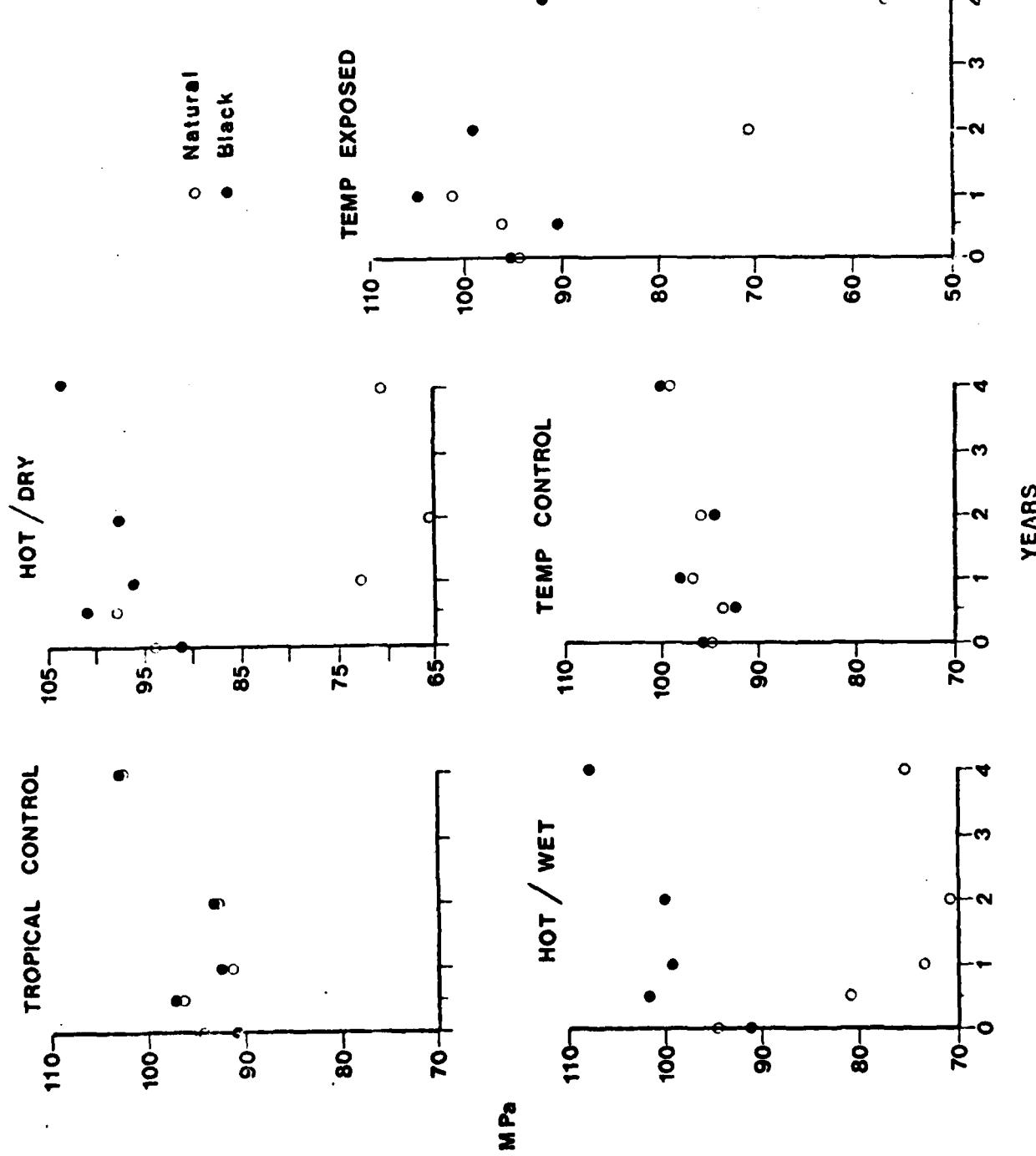


FIG 5 FLEXURAL MODULUS POLYSULPHONE

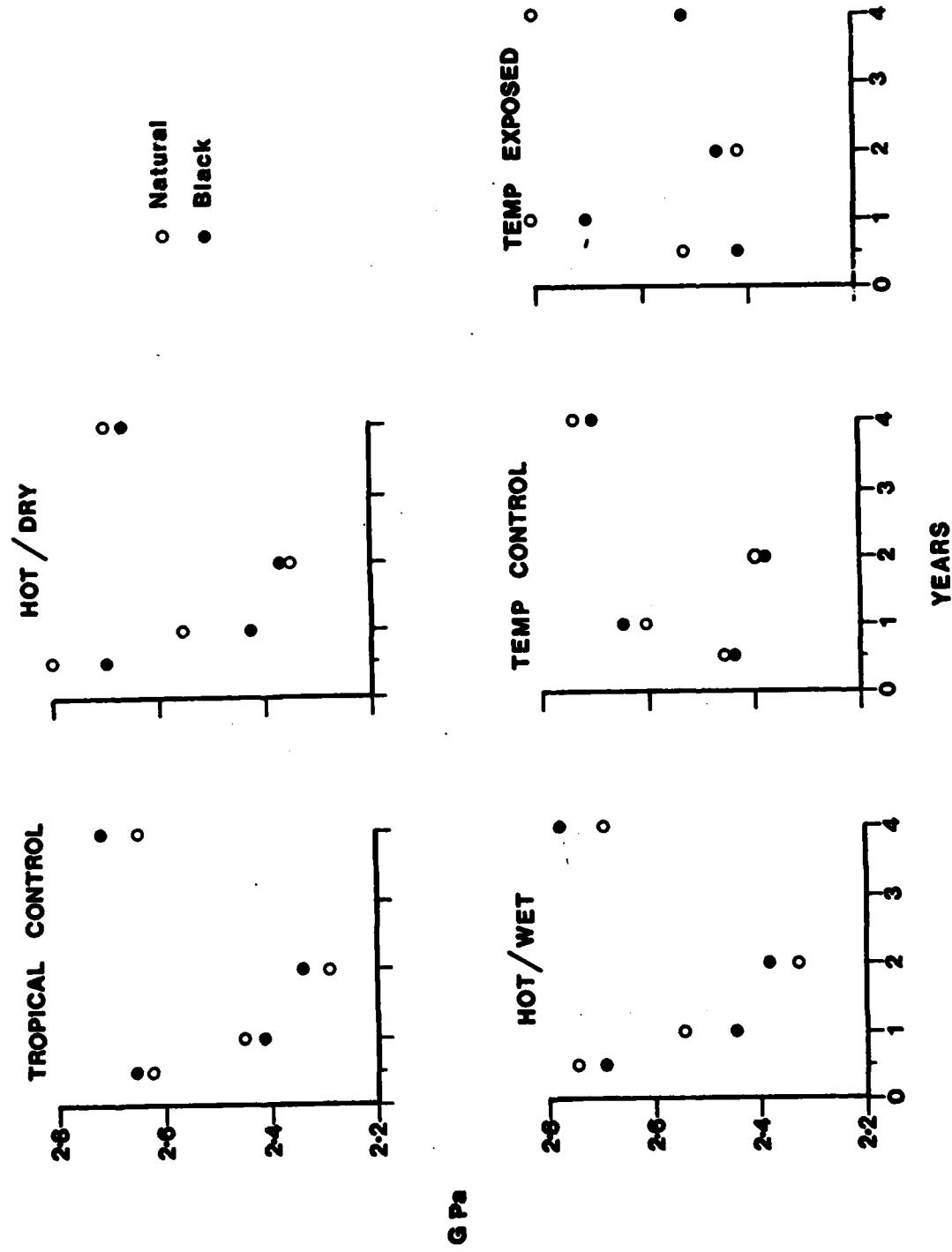
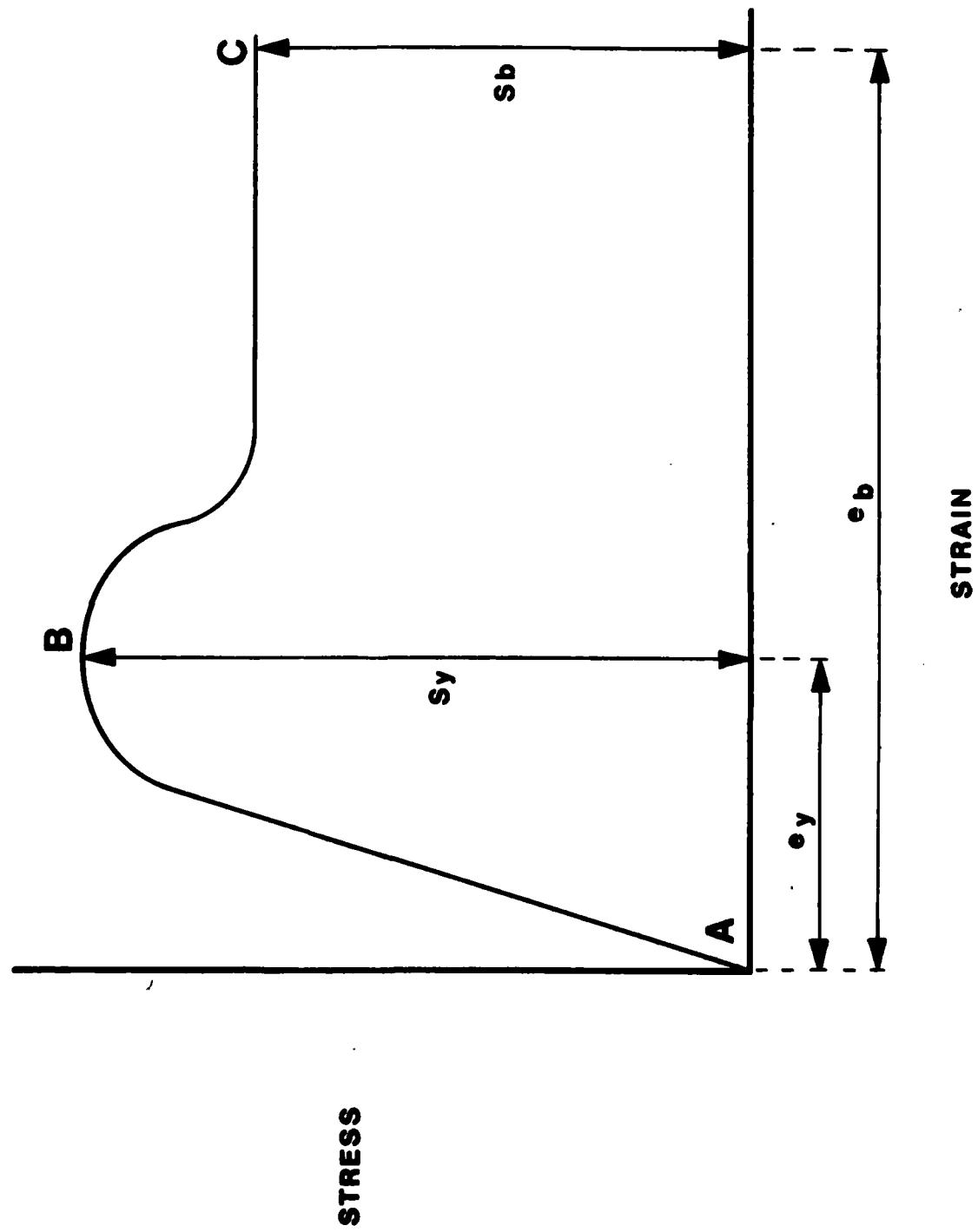


FIG 6 POLYSULPHONE STRESS / STRAIN CURVE



REPORT DOCUMENTATION PAGE

(Notes on completion overleaf)

Overall security classification of sheet Unlimited.....

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R),(C) or (S)).

1. DRIC Reference (if known)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification <u>Unlimited</u>
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Abstract <p>The report describes the effect of long term weathering on polysulphone. Both unpigmented samples and samples containing carbon black were exposed for up to 4 years at two tropical and one temperate site. Visual appearance, weight, tensile and flexural strength and electrical properties were recorded and used to monitor the effects of weathering on polysulphone.</p>			